Evaluation of Oil Remaining in the Intertidal from the *Exxon Valdez* Oil Spill

Project Number:	01543
Restoration Category:	Research and Monitoring
Proposer:	Jeffrey W. Short and Michael L. Murphy NMFS, Auke Bay Laboratory ABL Program Manager: Dr. Stan Rice NOAA Program Manager: Bruce Wright
Lead Trustee Agency:	NOAA
Cooperating Agencies:	Alaska Department of Environmental Conservation Alaska Department of Natural Resources Alaska Department of Fish and Game U.S. Forest Service U.S. Geological Survey
Alaska Sea Life Center:	No
Duration:	2 years
Geographic Area:	Prince William Sound, Gulf of Alaska
Injured Resource/Service:	Intertidal communities, Sediments

ABSTRACT

This project will assess the amount of oil remaining from the *Exxon Valdez* oil spill on shorelines within Prince William Sound. A stratified random sample of shoreline will be intensively sampled for surface and subsurface oil to estimate length of oiled shoreline, area and volume of oiled sediment, and volume of oil. Approximately 8 km will be sampled by digging more than 8,000 pits to discover and quantify subsurface oil.

INTRODUCTION

Oil from the March 1989 Exxon Valdez oil spill (EVOS) has been surprisingly persistent on some beaches. At the end of the 1992 cleanup season, natural processes were expected to disperse most of the oil remaining on shorelines. However, relatively unweathered oil remains today at a number of locations that were heavily oiled initially, and protected from dispersion by storm-generated waves. The extent of the remaining oil is unknown, and this uncertainty engenders public and scientific concerns about the effects the oil may continue to have on humans and on fauna that may become exposed to the oil either directly or indirectly. The project proposed here seeks to address these concerns by providing a quantitative estimate of the amount of shoreline (length, area, sediment and volume) that remains contaminated. This estimate will inform any assessment of the significance of the amount of oil remaining, and be the basis for further management (e.g., do nothing, restrict access or harvest; etc.).

Estimating the oil remaining on beaches affected by the EVOS in a cost-effective manner presents a considerable challenge. Previous attempts to address this problem have mainly relied on Shoreline Contamination Assessment Teams (SCAT), consisting of field teams performing comprehensive foot-surveys of impacted beaches. Although this approach may be useful for directing cleanup efforts immediately after a spill, it is less appropriate for producing a quantitative estimate of remaining oil contamination, especially long after a spill when most remaining oil is obscured from casual view. Instead, a stratified random/adaptive sampling design will be used to focus sampling effort in areas where oil most likely persists, while allocating some effort to discovering oil in areas where persistence is uncertain. This approach will guarantee a credible minimum estimate of remaining oiled area, and will provide a confidence interval for the most likely amount remaining throughout the affected region. This information is needed to predict oil persistence into the future and to determine associated risks to vulnerable biota.

This project will focus on oil remaining on beaches inside Prince William Sound (PWS). At this time, areas outside of PWS are not part of the proposed assessment. Previous Trustee-funded projects have examined oil persistence along the Kenai-Alaska Peninsula shoreline in 1999 (Project 99495) and in the vicinity of Kodiak Island in 1995 (Project 95027). These studies confirmed the persistence of localized oil. The value of a shoreline assessment outside PWS will be reevaluated after reviewing results from the current study.

This project will be divided into three phases: Phase 1 is development of the sampling design to be applied to the study area. Phase 1 was funded, and the study design described here is the product. Design alternatives were developed during summer 2000 and presented at a workshop in November 2000 for consideration by peer-reviewers, trustee agency representatives, and other stakeholders. Phase 2 is execution of the adopted sampling design inside Prince William Sound during spring/summer 2001. Phase 3 will be the closeout in FY02 involving analysis and report writing. This detailed project description presents the specific objectives, sampling design, and methodology for phase 2.

NEED FOR THE PROJECT

A. Statement of Problem

Although the persistence of relatively unweathered oil is clearly established on some beaches 10 years after the EVOS, the cumulative extent of remaining oiled beach is controversial. One estimate places the area of beach that remains contaminated by oil at less than 450 m^2 (Page 1999), but the basis for this claim has not been presented. Other studies suggest more extensive contamination (Brodersen et al. 1999; Hayes and Michel 1999; Irvine et al. 1999). These latter studies have often found relatively unweathered oil in the upper intertidal zone of beaches that are armored by boulders and beneath mussel beds that were initially heavily oiled (Babcock et al. 1998; Carls et al. 2000).

The extent of oil remaining on these beaches defines the lack of recovery for these sediments. The remaining oil may also impede recovery of injured species still exposed to it. This exposure includes direct contact with water contaminated by the remaining oil, or indirect contact through ingestion of prey contaminated by the oil. The fact that the remaining oil is often so unweathered indicates the oil is still a potent source of toxic polycyclic aromatic hydrocarbons (PAH), which elicit manifold adverse effects on biota exposed to them. These species may include black oystercatchers, clams, intertidal communities, mussels, Pacific herring, pink salmon, sea otters, subtidal communities, and harlequin ducks. In addition, subsistence uses, passive uses, recreation, and tourism may also be impaired because of speculation that the area remains contaminated.

B. Rationale

The plausibility of oil-exposure linkages connecting fauna at higher trophic levels with oiled habitat, as well as the propriety of additional restoration options, depend on an assessment of the amount of oiled habitat remaining in the spill area. Conversely, without this assessment, the public will continue to wonder how much of the spill area remains contaminated, and will likely make inappropriate decisions regarding resource use based on misperceptions about the extent of remaining oil. Also, scientists evaluating biological linkages to oil exposure will be less able to assess geographic correlation, compromising those studies.

Assessment of the extent of remaining oil should be done now to maximize benefits that may derive from the expected reduction in uncertainty regarding the extent of this oil.

C. Location

This project will be undertaken in PWS during 2001. Communities directly affected by this project include Cordova, Chenega, Tatitlek, Valdez, and Whittier. Benefits of the project will accrue especially to participants in subsistence and commercial fishing, scientists studying resource recovery in the region, and more generally to the public at large.

COMMUNITY INVOLVEMENT

Community involvement is crucial to the success of this project. Residents of the impacted area may have local knowledge of oil persisting in physical settings and locations that are not known to the investigators of this project. Communication of this knowledge will improve the accuracy of the assessment of oil remaining. Communities in the region will be canvassed, especially the Native and commercial fishing communities of Tatitlek, Chenega, Cordova, and Valdez, during winter 2001 to identify potential additional sampling compartments. This will involve presentation to these communities of a summary of where oil is presently known to persist, and an appeal for residents to identify any additional situations where oil has been recently observed. The final sampling design will address and incorporate these situations, to increase the chance that significant repositories of oil remaining in the area are not overlooked.

Local hire for field support and sampling will be used whenever possible during this project. This will likely include vessel and aircraft charters and labor during sample collection.

Results of this project will be summarized as a map depicting locations and extent of remaining oil discovered, together with a report summarizing the statistical estimate of the amount of oiled shoreline remaining. These materials will be accompanied by a press release announcing these findings to the media for general distribution. Public presentations will be given in Anchorage, Cordova, and Valdez to facilitate public review and commentary on the findings.

PROJECT DESIGN

A. Objectives

This project has three objectives:

1. Determine the amount of shoreline (length, surface area, sediment volume, and oil volume) that remains contaminated with oil in the *Exxon Valdez* oil spill area;

2. Determine the trend in the recovery of oiled shoreline in terms of oiled surface area and sediment volume;

3. Determine the trend in the recovery of subtidal sediments in terms of oil concentrations remaining at locations sampled in 1991; and

4. Verify the source of oil as the *Exxon Valdez* oil spill by "fingerprinting" and characterize the weathering state of the oil remaining in each of the strata sampled.

B. Methods

1. Phase 1

The goal of phase 1 is to produce a final sampling design to be implemented in the field the following spring. A set of design alternatives was developed by Auke Bay Laboratory staff and presented at a workshop on November 2, 2000. Attending the workshop were Trustee staff, chief scientist, and peer-reviewers for evaluation of suitability and cost-efficiency. Two geomorphologists, Drs. James Gibeaut and Dan Mann, were provided financial support to attend this workshop. Alternate designs suggested by workshop participants were considered and compared. Project objectives were discussed. Refinements to the design selected at the end of the workshop, along with a detailed study plan for phase 2 of this project, are included below.

2. Phase 2

Amount of Contaminated Shoreline in Prince William Sound

We will estimate the surface area and volume of contaminated shoreline based on a random sample of oiled shoreline identified in previous surveys from 1989 to 1993. To focus effort on areas most likely to still contain oil, we assume that oil remaining in 2001 mostly occurs in areas that had heavy or medium oil impacts. Heavy impact is defined as a band of surface oil >6 m wide or intertidal coverage >50%; medium impact is a band of surface oil 3-6 m wide or intertidal coverage 10-50%. These areas are identified in the EVOS GIS Database (ADNR 1992).

We define three sampling strata: 1) shoreline having heavy impact in 1990, 1991, or 1993 (ADNR 1992; Gibeaut and Piper 1998a); 2) shoreline with medium impact in 1990, 1991, or 1993; and 3) shoreline with heavy impact in 1989 but only light impact or less in later years. Emphasis is on shoreline showing heavy or medium impacts in surveys after 1989 because the surface contamination persisted at high levels later in those areas. Shoreline that had heavy impact in 1989 but only light-to-no impacts later are included in a separate stratum because they may contain subsurface oil even though surface oil improved over the 1989-1990 winter.

Heavy oil impact in 1990-1993 occurred in 150 shoreline subsegments (pieces of shoreline about 1 km long) having a total length of 166 km, of which 24 km was heavily impacted (Table 1). Most of these sites (134) were identified as being heavily impacted in the 1990 survey; 16 additional sites were identified in surveys in 1991 and 1993. Medium impact occurred in 270 subsegments in 1990-93, with a total length of 304 km and medium-impacted length of 46 km. Lengths of shoreline that had heavy impact in 1989 but only light-to-no impact later occurred in 238 subsegments and had a heavy-impacted length of 43 km.

Because the main purpose of this sampling design is to estimate hidden subsurface oil, the "sampling unit" must be of a size that is practical and ensures a thorough search. We define the basic sampling unit as a 100-m section of shoreline. We expect that a 100-m length of shoreline will be a workable area that can be thoroughly sampled for surface and subsurface oil in a single day. For this study, we divided all the shoreline lengths in each impact stratum into 100-m sampling units. Because the lengths of impacted shoreline vary in length, each stratum was further stratified into two substrata: 1) sampling units shorter than 100 m and 2) sampling units equal to 100 m. "Leftover" pieces of shoreline after dividing into 100-m units were included in the first substratum. Units in the first substratum (<100 m) are sampled in proportion to their length (i.e., randomly selected with probability of inclusion equal to the proportion of their length to the total length in the substratum), whereas sampling units in the second substratum (=100 m) are sampled with equal probability.

There are 317 units with heavy impact in 1990-1993, 672 units with medium impact in 1990-1993, and 538 units with heavy impact only in 1989 later (Table 1). Sampling units will be drawn randomly without replacement from each stratum.

At each randomly selected sampling unit, we will first thoroughly search for surface oil. Any surface oil discovered will be characterized and measured according to methods of Gibeaut and Piper (19981; Appendix 1). We assume that all surface oil deposits will be discovered and accurately measured. The sampling units, therefore, constitute a simple random sample, and the Horvitz-Thompson estimator (Thompson 1992) can be used to estimate total area of surface oil and its confidence interval for the three impact strata in Prince William Sound. An estimate of the total area (T) of surface oil is given by

$$\hat{T} = \frac{1}{N} \sum_{i=1}^{n} \left(\frac{y_i}{\pi_i} \right) \tag{1}$$

where N is the total number of sampling units in the population; n is the number of units in the sample; y_i is the area of oil in the i*th* unit; and π_i is the probability that the i*th* unit is included in the sample. Thompson (1992) provides an unbiased estimator of variance.

Because subsurface oil is hidden, the amount at each sampling unit will have to be estimated by random sampling. We will use an adaptive cluster sampling design because the adaptive design is more efficient than simple random sampling when the quantity to be estimated is distributed in rare patches (Thompson and Seber 1996). We will use a systematic initial sample with primary and secondary units (Thompson and Seber 1996) to provide uniform coverage of the shoreline area within the sampling unit.

Each 100-m sampling unit will be divided into 50 blocks by placing five vertical transects spaced 20 m apart, running from 6-ft to 16-ft elevation beginning from a starting point determined by geographic coordinates from the EVOS GIS Database (ADNR 1992). Thus, each block will be 20 m long by *W*/10 wide, where *W* equals the slope distance between 6 ft and 16 ft elevation. Each block will then be divided into secondary units whose size is determined by dimensions of a typical pit dug for discovering subsurface oil. Pits will be 50 cm x 50 cm square and 50 cm deep or to bedrock; thus, each secondary unit is 0.25 m^2. Two random starting points will be selected in the first block, and the pattern will be repeated in the other blocks. This pattern will provide two primary units (i.e., systematic samples) each consisting of 50 secondary units (i.e., 100 pits total). Where oil is discovered in the initial sample, additional pits will be excavated around the discovered oil to determine patch dimensions.

An estimate of the total subsurface oiled sediment area or volume is given by

$$\hat{\mathrm{T}} = \sum_{\mathbf{k}=1}^{K} \frac{\mathbf{y}_{\mathbf{k}}^{*}}{\alpha_{\mathbf{k}}} \tag{2}$$

Where K is the number of patches discovered; y^*_k is the oiled sediment area or volume in the k^{th} patch; and α''_k is the intersection probability of the k^{th} patch. Thompson and Seber (1996) provide an unbiased estimator of variance. Intersection probability is given by

$$\alpha_k = 1 - \left[\binom{N - x_k}{n} / \binom{N}{n} \right] \tag{3}$$

where N is the total number of primary units in the population (i.e., the total possible unique systematic samples); x_k is the number of primary units in the population that intersect the k^{th} patch; and n is the number of primary units in the sample.

Methodology for measuring subsurface oiled sediment area and volume will follow the 1993 shoreline assessment (Gibeaut and Piper 1998a; Appendix 1). In addition, approximately 150 samples of oiled sediment from the pits will be taken for gravimetric analysis to determine oil weight to calibrate visual estimates of oil weighting categories (Appendix 1). Pit dimensions will be measured to quantify mean and variance for each site. Locations of sampling units and oil patches will be determined by geographic positioning system for later mapping and entry into a geographic information system database.

To determine whether oil is present in a pit, trained personnel will look and smell for visible oil. We will attempt to develop a “wipe test” or other means that would be more reliable and objective than human eye and nose.

For analysis, data may be stratified by shoreline type if doing so increases precision of the estimates of total oil. Shoreline type is based on the Environmental Sensitivity Index (ESI) and classifies shoreline locations according to geomorphology and exposure. Heavily impacted locations in 1990 were primarily of five shoreline types: 1) exposed rocky shores; 2) exposed wavecut platforms; 3) mixed sand and gravel beaches; 4) gravel, cobble, boulder beaches; and 5) sheltered rocky shores (Table 2). The distribution of heavy impacts with respect to shore type in 1990 appeared to be random, as it was similar to overall distribution of shore types in the spill area (Table 2). In 1993, however, oil residues were principally found in areas with boulders and bedrock and under mussel beds (Table 3). Thus, all shoreline types had equal probability of being oiled, but shoreline types with boulders and mussel beds retained oil longer.

Detailed information on shore type will be taken at each sampling unit so that relationships between oil retention and shore type can be examined. Data currently available in the EVOS GIS database (ADNR 1992) are not detailed enough to allow for stratification by shore type prior to sampling.

Power Analysis

The estimate of the total amount of oiled shoreline derived from this project will contain two components of variance: 1) variance due to variation among shoreline areas used to extrapolate to the total, and 2) variance due to sampling error at each beach where oiled area and volume are estimated. We assume that <u>surface</u> oil will be measured without error at the sampling sites, but <u>subsurface</u> oiled sediment will be estimated by an adaptive sampling design and, therefore, have an associated sampling error. For subsurface oil, both components of variance must be accounted for, through bootstrapping or other procedure, to provide a point estimate and confidence interval for total amount of subsurface oiled shoreline.

The power of the design to estimate total oiled shoreline can be evaluated based on data from the 1993 survey (Gibeaut and Piper 1998b). In this analysis, we assume that the amount of oiled sediment at each sampling unit was measured without error. In the 1993 survey, the survey appears comprehensive, and the principal investigator is confident that all significant oil deposits were discovered (Gibeaut, pers. comm.); thus, this assumption appears valid. If instead, oil patches were estimated by random sampling, additional variance due to sampling error at the beaches would decrease power of the design.

The sample size n required to estimate the population total to within proportion r of the true value, with probability 1 - α ", is given by

$$n = 1/\ (r^2/z^2c^2 + 1/N),$$

where n is number of samples, r is relative difference between the estimate and the true value, z is the upper α"/2 of the standard normal distribution, c is the coefficient of variation s/mean, and N is the total number of sampling units in the population (Thompson 1992).

The 1993 data for surface oiled area and subsurface oiled volume in 45 sites were lognormally distributed. The data, therefore, were transformed to natural logarithms to calculate variance (Table 4). Using the coefficient of variation for subsurface oiled volume from the 1993 data, we calculated the required sample size to achieve various levels of relative precision *r* for an estimate of total oiled sediment volume (log scale) with error probability α "of 10%.

Results for the 150 heavily impacted subsegments, for example, indicate that the confidence interval decreases rapidly as sample size increases toward about 20-30% of sampling units and decreases more slowly at greater sample sizes (Fig. 1). A sample size of about 20% of sampling units would provide an estimate within ±20% of the true value for total subsurface oiled volume in log scale. A sample size of about 50 subsegments (30% sample) would provide an estimate within ±14% of the true value. Because precision is expressed in logarithms, actual confidence intervals after converting back to original scale will be somewhat greater and asymmetrical.

The preceding power analysis does not account for the additional variance due to sampling error at each sampling unit. No data are currently available to assess this variance. Use of the adaptive sampling procedure to discover and measure hidden subsurface oil, however, will provide an estimate of this additional variance.

For the adaptive sampling design used to estimate subsurface oil at each sampling unit, the most important consideration is that the sampling effort be sufficient to provide confidence that hidden oil, when present, will be discovered by the initial systematic sample. The probability of discovering hidden oil when present depends on the width of the beach (i.e., slope distance from 6 ft to 16 ft), number of primary units in the sample, and shape and distribution of oil patches. Width of the beach determines the area to be sampled and the density of pits within each 100-m sampling unit.

To examine likelihood of discovering oil patches under different conditions, we determined intersection probabilities α''_k for several hypothetical scenarios. For example, consider a beach that is 100 m wide with a band of buried oil 2 m wide and 60 m long (Fig. 2). In this case, each block in the sampling unit is 10 m wide by 20 m long, so that there are 800 possible primary units in the population. By inspection, the oil band intersects 480 primary units. By Equation (3), therefore, the probability of discovering the oil patch with one primary unit (50 pits) equals 60%; with two primary units (100 pits), probability is 84%; and with three primary units (150 pits), probability is 94%. Although a 60% probability might be considered adequate, a minimum of two primary units is required to provide an unbiased estimate of variance (Thompson 1992). If the same beach were half as wide (50 m slope distance), intersection probability with even one primary unit would be 100%. Thus, if significant patches of oil exist in the sampling units, we anticipate a high probability of encountering them with two primary units (100 pits per 100-m sampling unit). If a beach were much wider than 100 m, we would increase the number of primary units in the sample to provide adequate coverage.

Sampling Effort and Allocation

We propose to allocate approximately two-thirds of the sampling effort to shoreline that was still heavily impacted in 1990-1993 (Stratum 1), one-quarter of effort to the shoreline that was medium impacted in 1990-1993 (Stratum 2), and about 5% of effort to shoreline with heavy impact in 1989 only (Stratum 3) (Table 5). The remaining effort will be allocated to any high-priority sites suggested by agencies or local communities as special areas of concern. This effort allocation can be adjusted as sampling progresses if, for example, it appears that greater effort in the medium-impact stratum would provide a more precise estimate of oiled shoreline. Adjustments will also be considered if it appears that geomorphologically identifiable units on the high impact beaches are consistently devoid of oil, so that effort could be more usefully concentrated in units when encountering oil is more likely.

Based on the power analysis above, a sample of about 20% of shoreline in the heavy-impact stratum should provide good precision for the estimate of total oiled shoreline area and volume in this stratum. In this stratum, we would sample 55 sampling units (18 units <100 m and 37 units = 100 m) with a total length of about 5 km. We would also sample 2 km of shoreline in Stratum 2 (medium impact), 0.5 km in Stratum 3 (heavy impact in 1989 only), and about 0.5 km of shoreline of particular concern (Table 5). The total shoreline sampled would be about 8 km, involving digging more than 8,000 pits. This effort provides a thorough coverage of the spill area.

We estimate that a crew of six (one supervisor, one assistant, one archeologist, and three diggers) could complete sampling of about 100 m per day, depending on sampling difficulty, complexity of discovered oil distribution, and travel time between sampling units. Thus, the 8 km of sampling units should be completed in eight 12-day cruises (96 charter days) accounting for travel to and from base and weather days. For comparison, the 1993 survey worked one crew for eight 1-week cruises and surveyed a total of about 19 km of shoreline but with a much lower number of pits (Gibeaut and Piper 1998a, b).

The total effort and funding requirements for this project are quite large. Additional objectives or a change in priorities would cause a shift in effort allocation but probably not an increase in total effort. For example, if more effort is desired at locations considered important by communities, less effort would be available to sample random locations, and statistical precision would decline.

Recovery Trends

The trend in recovery of oiled shoreline will be measured in two ways. First, we will resurvey at least 10 randomly selected sites from the 45 sites that were used in the 1993 shoreline assessment (Gibeaut and Piper 1998a,b). These sites have oiling and cleanup data from 1989 through 1993. At these sites, we will duplicate the sampling procedures of Gibeaut and Piper (1998a, b), as well as conduct the adaptive sampling design to compare results of the two designs.

A second means of determining recovery trend will be to resurvey some of the stations with permanent transects established in 1989 by NOAA and ADEC and resurveyed in 1993 by Gibeaut and Piper (1998a). These stations include high-energy boulder and cobble beaches; moderate-energy boulder, cobble, and pebble beaches; and sheltered set-aside stations. This type of survey entails measuring the profile along a line oriented perpendicular to the shoreline trend and visually estimating sediment and oiling conditions (Gibeaut and Piper 1998a). Resurveying 15 of these stations will provide quantitative data on erosional and depositional processes related to degradation and dispersal of oil.

The recovery trend of subtidal sediments will be evaluated by resampling 5 locations that were last monitored in 1991 (O'Clair et al. 1996). These locations include Herring Bay, Northwest Bay, Olsen Bay, Sleepy Bay, and Snug Harbor. Olsen Bay was a control location outside the spill path, and the others were heavily oiled, with oil from the spill detected in subtidal sediment at them in 1991. At each of these locations, transects were sampled at 0, 3, 6, 10, 20, 40, and 100 m below MLLW. Sediment samples will be collected from each of these transect sites at each location for a total of 35 samples, using collection methods identical with those used in the 1991 survey in conjunction with the shoreline assessment sampling described above during summer 2001. These samples will be analyzed by GCMS in 2003, and the data will be evaluated by the hydrocarbon source recognition methods developed by Short and Heintz (1997) for these samples. Comparison of results with the 1991 data will permit assessment of oil persistence at these locations.

Oil Source -- Fingerprinting

To determine condition of remaining oil and whether it still matches *Exxon Valdez* oil, we will collect 24 sediment samples with visible subsurface oil from pits at different sampling sites. These samples will be analyzed by GC-MS to determine whether PAH composition matches weathered *Exxon Valdez* oil. A weathering index (Short and Heintz 1997) will be determined for each sample.

C. Contracts and Other Agency Assistance

Funds will be provided to the U.S. Forest Service to hire a certified archeologist for a 5-month appointment to participate in field sampling and to ensure compliance with the State Historic Inventory Program administered by the Alaska Department of Natural Resources. A contract will be provided to Dr. Jim Gibeaut of the Bureau of Economic Geology, University of Texas, to conduct training of personnel so that methodology will be comparable to previous surveys, and to analyze the recovery trend in PWS based on a resurvey of 15 transect sites established by ADEC/NOAA in 1989. A contract will be provided to conduct an Environmental Analysis if required under NEPA.

SCHEDULE

A. Measurable Project Tasks for FY01

FY01:

Nov. 2:	Convene planning workshop in Anchorage to develop study design.
Nov. 20:	Incorporate peer-review comments into final DPD and submit for funding consideration by the Trustee Council in December. (End Phase 1).
Nov 30 – Apr 15:	Present summary of known remaining oil deposits inside PWS and canvas communities for local knowledge of persistent oil. Identify sampling locations of community concern.
Apr 15 – May 15:	Hire and train field personnel.
May 15 – Sep 30:	Collect field data and samples. (End Phase 2).

B. Project Milestones and Endpoints

FY02: Closeout.

Oct 1 – Apr 15:	Analyze phase 2 data and samples; enter data on GIS database.
Apr 15 – Sep 30:	Produce map depicting sampled locations; prepare final report and journal publications.

C. Completion Date

September 30, 2002

PUBLICATIONS AND REPORTS

No publications will be submitted in FY01. We anticipate that three research papers will be submitted to peer-reviewed scientific journals in FY02. Probable titles of these papers will be "*Amount of oil contamination in Prince William Sound 11 years after the Exxon Valdez oil spill*," "*Trend of recovery of subsurface oil after the Exxon Valdez oil spill*," and "*Identification and weathered condition of remaining Exxon Valdez oil 11 years after the spill*."

PROFESSIONAL CONFERENCES

None Planned for FY01.

NORMAL AGENCY MANAGEMENT

If the oil spill had not occurred, neither NOAA nor the cooperating agencies would be conducting this project.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This project will be coordinated through participation of the cooperating agencies. Formal coordination commenced at the November workshop in Anchorage. All of the previous Trustee-funded studies on oil persistence in the spill region have been performed under the auspices of these agencies, and it is presumed that local knowledge is the only significant source of additional information relevant to this project outside these agencies.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

None

PROPOSED PRINCIPAL INVESTIGATOR

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PRINCIPAL INVESTIGATORS

Jeffrey W. Short

Education: M.S. (Physical Chemistry)

Relevant Experience:
1989- Present: Established and managed the hydrocarbon analysis facility at ABL to analyze hydrocarbon samples generated by the *Exxon Valdez* NRDA effort (about 20% of these samples were analyzed at ABL).
1989 - 1992: Principal Investigator, Exxon Valdez project Air/Water #3: Determination of

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petroleum hydrocarbons in seawater by direct chemical analysis and through the use of caged mussels deployed along the path of the oil spill.
1991 - 1996: Principal Investigator, Exxon Valdez project Subtidal #8: Development of computer-based statistical methods for global examination of sediment and mussel hydrocarbon data produced for the Exxon Valdez NRDA effort for systematic bias, and for identification of probable sources of hydrocarbons.
1996 - present: Principal Investigator, Restoration Project 290, Database Management.

Michael L. Murphy

Education: M.S. (Fisheries Science)

Relevant Experience:
1981 - 1995: Conducted extensive field studies on effects of logging on anadromous fish habitat in Southeast Alaska, leading to legislative changes in forestry practices.
1995 - 1997: Principal Investigator, Exxon Valdez project 97194, Recovery of Pink Salmon Spawning Areas after the *Exxon Valdez* Oil Spill.

OTHER KEY PERSONNEL

1. Patricia Harris, Zoologist, Auke Bay Laboratory, will assist in supervising field sampling, data analysis, , and coordinate interactions with local communities.

2. Mandy Lindeberg, Fisheries Biologist, Auke Bay Laboratory, will assist in supervising field sampling, data analysis, and writing.

3. Jerome Pella, the senior biometrician at the Auke Bay Laboratory, will consult on sampling design and data analysis.

4. Marianne See, Alaska Department of Environmental Conservation, will facilitate coordination with State of Alaska agencies.

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Table 1. Number and length of shoreline subsegments with either heavy or medium oil impact in 1990-1993, or with heavy impact in fall 1989 but light-to-no impact afterwards.

	Number of Subsegments with Impact	Total Length of Impact (m)	Number of Sampling Units
Heavy impact in 1990, 1991, or 1993	150	24 km	317
Medium impact in 1990, 1991, or 1993	270	46 km	672
Heavy impact in 1989 only	238	43 km	538

Table 2. Frequency of heavily oiled locations by shoreline type in spring 1990 and overall frequency of shore types in the spill area. Locations are pieces of shoreline with consistent geomorphology and oiling history.

Shoreline type	% Frequency of heavy impacts in 1990	% Frequency of shore types in the spill area
Exposed rocky shores	18	18
Exposed wavecut platforms	9	8
Fine-grained sand beaches	0	0
Coarse-grained sand beaches	0	0
Mixed sand and gravel beaches	29	23
Gravel, cobble, boulder beaches	18	18
Exposed tidal flats	0	0
Sheltered rocky shores	25	28
Sheltered tidal flats	1	3
Marshes	0	1
Total locations (n)	332	13,025

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Table 3. Surface and subsurface oiled sediment observed in the 1993 survey in relation to shore type. Data are from Gibeaut and Piper (1998b).

	Surface oiled sediment		Subsurface oiled sediment	
Shore type	Area (m^2)	% of total	Volume (m^3)	% of total
Wavecut platform	3,035	29	127	3
Sheltered rocky	2,376	22	86	2
Exposed rocky	2,166	21	714	14
Boulder/gravel beach	2,140	20	3,413	67
Sheltered tide flat	836	8	4	0
Mixed sand/gravel beach	9	0	25	0
Mussel bed	0	0	722	14
Total	10,562	100	5,091	100

Table 4. Estimates of the mean and variance of log-transformed (ln(x + 1)) surface area and subsurface volume of oiled sediment in 1993 (Gibeaut and Piper 1998b). Data are total surface area and subsurface volume per subsegment.

	Surface oil (m^2)	Subsurface oil (m^3)
Mean0	4.05	3.32
Standard deviation *s*	2.05	2.07
Variance s^2	4.20	4.28
Coefficient of variation	0.51	0.62
Number of subsegments	45	45

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Table 5. Distribution of effort among sampling strata.

Stratum	% Effort	Shoreline to be sampled (km)	Shoreline in Stratum (km)	Sample fraction (% shoreline)
Heavy impact, 1990-1993	63	5	24	21%
Medium impact, 1990-1993	25	2	46	4%
Heavy impact, 1989 only	6	0.5	43	1%
Areas of concern	6	0.5		
Total	100	8.0		

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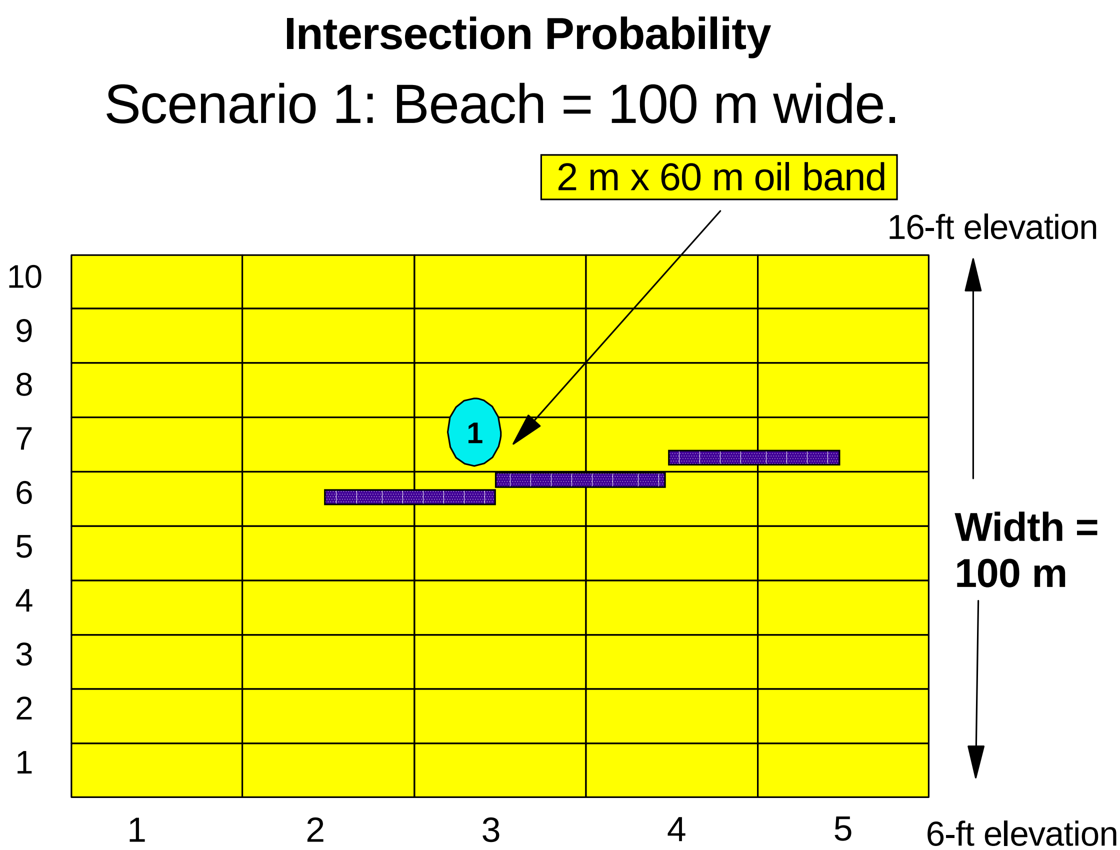

Figure 2. Analysis of the intersection probability resulting from application of an adaptive cluster sampling design with a 100-m sampling unit and an initial systematic sample. The sampling unit is divided into 50 blocks, and random starting points are selected in the first block and repeated in all other blocks. A hypothetical scenario is illustrated in which the beach is 100 m wide (slope distance from 6 ft to 16 ft elevation) and the site contains a band of subsurface oil 2 m x 60 m. There are 800 possible unique starting points for a systematic sample of 0.5 m x 0.5 m pits. The intersection probability is 60% with one primary unit (50 pits), 84% with two primary units (100 pits), and 94% with three primary units (150 pits). Although a 60% probability might be considered adequate, a minimum of two primary units is required to provide an unbiased estimate of variance (Thompson 1992).

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Appendix 1. Methods used by ground surveys to estimate oil coverage in 1993 (Gibeaut and Piper 1998).

The 2001 survey will use the same techniques as previous surveys to measure the area of discovered oiled surface sediment and volume of discovered subsurface oiled sediment (Exxon Corporation 1991; Gibeaut and Piper 1998). Observed oil distribution will be recorded on field maps and forms. Observed oil will be classified according to type and distribution (Gibeaut and Piper 1998). Field classification of oil type and percent cover was designed for consistent collection of qualitative field data. The categories are broad and reflect the problems associated with making observations in areas where oil cover and beach geomorphology vary.

The size of oiled locations will be measured with a meter tape, and the percent oil cover within the area will be visually estimated. Amount of surface oil cover will be estimated by multiplying the area of oiling by the percentage value for field categories for surface oil coverage (Gibeaut and Piper 1998).

Pits will be dug to delineate subsurface oiling areas, and the pits will be plotted on field maps with a distance scale. The average oiling thickness will be calculated for each type of oil in a location, and this number will be multiplied by the area measurement of that type to yield an oiled-sediment volume. The oiled-sediment volume will be multiplied by a “weight” corresponding to the relative concentration of the oil. The weighted oiled-sediment volume (WOSV) is a way to track relative amounts of oil.

$$WOSV = 5_{VOP} + 4V_{HOR} + 3V_{MOR} + 2V_{LOR},$$

where VOP is volume of oil pore (OP) sediment; VHOR is volume of heavy oil residue (HOR); etc.

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